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Searching for Exotic Particles at the LHC with Dedicated Detectors.

J. L. Pinfold, [a]*

[a]Centre for Subatomic Research, University of Alberta,
Edmonton, Alberta T6G 2N4,Canada

The LHC will open up a new energy regime where it may be possible to observe physics beyond the Standard Model. Therefore the search for exotic phenomena, such as: magnetic monopoles, massive stable particles; slowly decaying exotic particles; highly penetrating particles; and, free quarks and gluons, will be an important part of the LHC physics program. We propose that the search strategy for exotics planned for the main LHC detectors be extended with modest dedicated experiments designed to enhance the physics reach of the LHC. We shall use two examples to illustrate this thesis. First, a passive, plastic track-etch detector "ball" designed to detect highly ionizing particles and measure their Z/β. Such a detector is currently the subject of a Letter of Intent to the LHCC from the MOEDAL collaboration. Another (active) small acceptance detector – protected by shielding and monitoring an extended decay zone – specifically designed to detect massive stable particles and detect slowly decaying particles, is described. The use of such a detector at the LHC, has recently been proposed.

1. Introduction

The dedicated detectors proposed here are designed to look for a *class* of phenomena such as highly ionizing particles, or slowly decaying particles. Essentially, the philosophy of such detectors is to allow the precise and unambiguous measurement of experimental signatures that are inconsistent with Standard Model physics with a minimum of only a very few observed events.

Two examples are used to illustrate the proposed use of dedicated detectors. First, a passive, plastic track-etch detector "ball" designed to detect highly ionizing particles and measure their Z/β. Such a detector is currently the subject of a Letter of Intent to the LHCC from the MOEDAL collaboration. Another (active) small acceptance detector – protected by shielding and monitoring an extended decay zone – specifically designed to detect massive stable particles and detect slowly decaying particles, is described. The use of such a detector at the LHC, has recently been proposed. The hypothetical deployment of such a detector as part of an LHC detector is considered.

It is envisaged that the active detector is a conventional "fixed target" array involving: veto and TOF hodoscopes; tracking detectors; as well as electromagnetic and hadronic calorimeters, placed at roughly 7^o to the beam axis.

As we shall see the charged and neutral, exotic, particles we could seek may originate from many sources: Gauge Mediated SUSY breaking models [1]; R-Parity violating models [2]; models that predict the existence of heavy unstable neutrinos [3]; etc.

2. The Physics Case

Three physics cases are considered here where small (compared with the main experiments) dedicated detectors can potentially be used to extend the physics range of the LHC.

2.1. Exotic Highly Ionizing Particles

There are numerous extensions to the Standard Model such as: SUSY; compositeness, L-R Symmetric Models, Superstring, GUTS, etc. All of these theoretical models predict the existence of as yet unobserved exotic particles. Excellent reviews of this topic are given elsewhere [4] Here we will concentrate on the detection of magnetic monopoles and dyons at the LHC using the passive MOEDAL detector.

The search for the magnetic monopole [5] has been a quest of particle physics ever since monopoles were hypothesized by Dirac in the

*For the MOEDAL Collaboration

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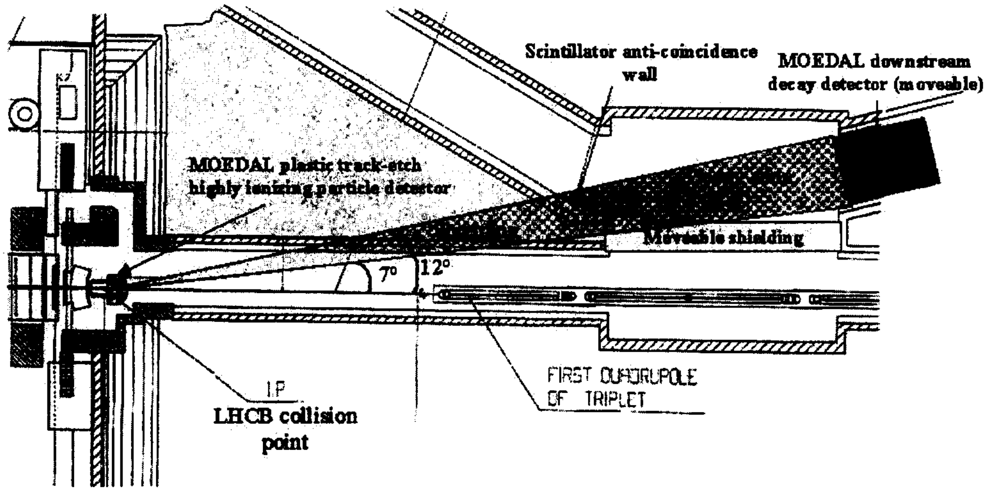

Figure 1. A schematic view of a detector for heavy stable and quasi-stable exotic particles. The detector is deployed in this case in the region UJ84 behind a minimum of 16m of rock/concrete shielding with a decay zone of similar length. The MOEDAL passive detector for highly ionizing particles is also shown deployed around the LHCB vertex chamber.

1930's in order to symmetrize Maxwell's equations and explain the quantization of electric charge. Modern gauge theories with their inherent monopole solutions have raised the status of monopoles from a useful and elegant hypothesis to a requirement of the theory. Unfortunately, Grand Unification magnetic monopoles, with masses of the order of 10^{15} GeV are well beyond the reach of any presently conceivable man-made accelerator. Never-the-less there are models where monopoles could appear in a mass range accessible to the LHC. Examples include: the model of Weinberg et al [6] and a Superstring model [7] where in principle, monopoles/dyons with a mass low enough to be detected at the LHC are hypothesized.

There are two distinct signatures that can be utilized to search for monopoles or dyons at the LHC. The first is its unusual trajectory in a solenoidal magnetic field. The second is its highly ionizing nature. For example, the ionization energy loss of a relativistic monopole with a single Dirac charge is 4700 times that of a singly charged particle. It is possible that these search signatures can be used in general LHC detectors such as ATLAS, CMS and LHCB. However, the amount of material surrounding the beam-pipe in these detectors reduces significantly their sensitivity to highly ionizing particles. A simple cost effective and efficient detector of highly ionizing particles is a passive plastic track-etch detector. This type of detector has been used in many previous monopole searches at particle colliders such as LEP [8] ; the Tevatron [9] ; and, KEK[10] .

2.2. Slowly Decaying Exotic Particles

There are many hypothetical sources for new particles that could decay slowly – that is, outside of the main detection region of conventional detectors, for example, heavy 4th generation neutrinos[3]. We shall concentrate here on Supersymmetry, which many consider to be the best-motivated successor to the Standard Model.

If Supersymmetric models are indeed nature's choice the LHC could be a "factory" for producing neutralinos if squarks and/or gluinos exist below a mass scale O(1) TeV [11]. A recent estimate, with various assumptions on the values of the relevant SUSY parameters, indicate that a model invoking Gauge Mediated SUSY Breaking (GMSB) can give production rates of 10^6 to 10^9 neutralinos/yr for a luminosity of $L = 10^{34} cm^{-2} s^{-1}$. It is usually assumed that the lightest neutralino ($\tilde{\chi_0}$) is stable. However, the $\tilde{\chi_0}$ will be unstable if R-parity is violated or if lighter superparticles such as the gravitino or axino exist. The decay signal could be missed in conventional collider experiments if the cross-section is small and/or the decay length is extremely long.

The decay product of an unstable neutralino can be measured in a detector placed at the end of a long decay region deployed at a small angle to the beamline and protected from conventional backgrounds by extensive shielding. The delayed arrival time at the detector and decay products that do not point to the interaction region, can provide a clear signature for slowly decaying $\tilde{\chi_0}$s. In the case of the decays, $\tilde{\chi_0} \to \gamma\tilde{G}, \gamma\tilde{a}$, where the neutralino decays into a photon and a gravitino or a photon and an axino, the mass of the decaying particle can be estimated by using the correlation between the energy and the arrival time of the decay product [11].

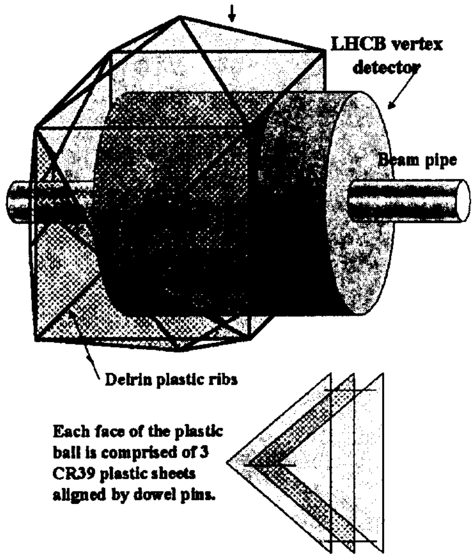

Figure 2. A conceptual design for the MOEDAL plastic track-etch-stack detector deployed around the LHCB vertex detector. The precise details of construction of the detector awaits a final approval from the LHCB collaboration.

2.3. Heavy Stable Particles

Many extensions to the Standard Model (SUSY, Compositeness, GUTs, etc.) allow for (quasi) stable heavy exotic particles[12] . Common features of this class of exotic particle are large mass; $\beta < 1$; long lifetime, $> 10^{-7}$s; electric charge a fractional or integer multiple of the proton charge. Examples of such phenomena are heavy quarks belonging to representations of SU(3)[13] and charginos that in some SUSY models behave like massive stable exotic particles [14].

Very heavy particles can be highly penetrating since the fractional energy loss by ionization is much smaller for a heavy particle. For example, very massive singly charged particle highly penetrating with $\beta > 0.3$ would register in the muon chambers of the main LHC detectors. There is already at least one scheme to use the ATLAS detector muon system as a TOF counter capable of triggering on such particles [15]. The stable exotics discussed here can have significant ionizing power even when they are singly charged. A passive plastic track-etch detector such as the MOEDAL passive detector for highly ionizing particles, equipped with sensitive CR39, would be able to register the presence of such particles with a $Z/\beta \geq 7e \to 8e$ and enable a determination of the effective Z/β the particle. In this case the dE/dx of the particle would be so large that it would not penetrate the calorimetry of the LHC detector.

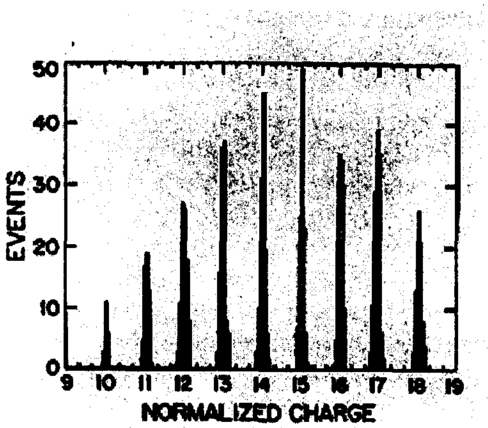

Figure 3. Resolution of charge determination using CR39 track-etch plastic.

A charged Massive Stable Exotic particles MSE could penetrate the shielding surrounding the MOEDAL slow decay detector, where its dE/dX and TOF could be measured, essentially background free. Also, MSE particles can be very highly ionizing enough to register in the passive plastic MOEDAL detector.

3. Examples of Dedicated Limited Acceptance Detectors for the LHC

3.1. The MOEDAL Passive Track-Etch Highly Ionizing Particle Detector

The signature for highly ionizing particle production is the production of collinear etch pits in the three plastic layers of the MOEDAL plastic track etch detector. In the case of the Dirac monopole (and monopoles predicted to exist by many Gauge Theories) the magnetic charge is an integral multiple n of $g_o = hc/2e = 68.5e$ and its ionization rate is very high, for $\beta > 0.2$ [16],

$$-\left(\frac{dE}{dx}\right)_m = \left(\frac{ng\beta}{e}\right)^2 \left(\frac{dE}{dx}\right)_e \qquad (1)$$

and $-\frac{dE}{dx}_m = K\beta$ for $3 \times 10^{-4} < \beta < 0.2$.

Where $(dE/dx)_e$ is the energy loss for a proton and $K = 33n^2$ GeV/cm for plastic. The only background to penetrating highly ionizing objects arises from spallation products within the detector. If we demand collinear etch-pits through the three layers of the MOEDAL plastic hemisphere detector this background becomes essentially zero.

The proposed design of the highly ionizing particle detector is depicted in Figure 2. It consists of an assembly of CR-39 track-etch detectors with a charge detection threshold of $Z/\beta > 5$. The detector consists of three layers of CR-39 plastic sheets each of thickness 1.4 mm deployed around the LHCB intersection region. It is possible to make measurement of particles with large Z/β as can be seen from Figure 3 [16]. The detector design was chosen to ensure that any highly ionizing particles produced traverse the track-etch detectors at as near normal incidence as possible in order to obtain maximum sensitivity.

The passage of a highly ionizing particle through the track-etch detector is marked by an invisible damage zone along the trajectory. The damage zone is revealed as a cone shaped pit when the surface of the plastic detector is etched in a controlled manner using a hot sodium hydroxide solution. The depth of the etch pit is an increasing function of the particle's Z/β. The alignment of the etch pits in each sheet of the stack allows the trajectory of the particle to be traced. Particles with standard charges produced in the pp interaction will not be recorded.

A powerful feature of etchable track detectors is that their response depends only on the dose within 10^{-6} cm of a particle's trajectory and is independent of dose rate. However, a limitation that must be taken into account is degradation due to radiation damage. At hadron colliders the most severe limitation is the accumulation of short range tracks of highly ionizing recoil nuclei produced in hadronic interactions in the detector material. Previous measurements [17] have shown that the limiting density of tracks of short range spallation recoils at one surface is $\sim 10^8 cm^{-2}$ below which the track of a long range highly ionizing particle can still be detected. Such detectors have already been used at the Fermilab hadron collider with integrated luminosities of $\sim 10^{34} cm^{-2}$. This is approximately the maximum useful luminosity that a single CR39 detector could tolerate in the experimental configuration employed

The peak luminosity expected at the LHCB intersection region is envisaged to reach $\sim 10^{32} cm^{-2} s^{-1}$. Thus the integrated luminosity for one year could reach as high as $10^{-39} cm^{-2}$. One must be prepared for peak luminosity running where, considering the maximum density of $10^{-8} cm^{-2}$ tracks from short range spallation products, we have to make up a factor of 10^5 for one year of exposure at the LHCB intersection region.

We have four basic strategies which can be used to improve the radiation hardness of the CR39 stacks. First, one can utilize Lexan as the main sensitive medium since it is a factor of 125 more radiation tolerant [18]. Second, placing the detectors further from the beampipe means that the density of spallation products falls - assuming these are due to high energy tracks from the intersection region . One can gain a factor of 40 reduction in the number of spallation tracks per cm^2 – over the spallation track density expected in plastic deployed around the beampipe – by placing the plastic of the MOEDAL detector $\sim$ 50cm from the intersection region. Third, one can simply change the plastic at regular intervals throughout the year. The design of the passive detector allows the plastic track-etch stacks for the whole detector to be replaced within a few hours. Also, the LHCB intersection region is easily accessible. We estimate that we can gain a factor of $\sim$ 5 in the maximum achievable integrated luminosity due to this procedure.

One can gain a fourth factor in radiation resistance by removing the plastic from the vicinity of the intersection region using remote control, to await an access when the plastic can be changed or redeployed.

3.2. Detecting Slowly Decaying and Heavy Stable Exotic Particles

If the dedicated detector for slowly decaying exotic particles is to provide any significant increase in the discovery potential of the main LHC detectors it will be because of: its long decay path (16m- 20m); large distance from the interaction point (45m); shielding (~20m); superior gamma pointing resolution ($\sim 0.1^0$); and, precise tracking far from the vertex region. The detector is also designed to have very good TOF resolution and the ability to measure dE/dx over a large range. The first iteration on the placing of slow decay detector is shown in Figure 1. It is envisaged that a similar space could be found near to a *high luminosity intersection region.* The sensitive volume of the active slow decay detector detector is protected by muon-veto walls that filter out essentially all of the remaining conventional background. It is important that the detector makes a small angle to the beamline as the flux of neutralinos is peaked in the forward backward direction.

Although further studies have to be made, the deployment of the detector in the UJ 84 "room" near to point 8 (shown in Figure 1) would appear to satisfy the requirements without any significant need for modification to existing infrastructure. In order, to track charge particles, measure the energy and angle of photons, measure hadronic energy and perform TOF measurements the "fixed target beam dump" type detector shown in Figure 4 is envisaged.

A prime signature for the GMSB decays $\tilde{\chi}_0 \rightarrow \gamma\tilde{G}, \gamma\tilde{a}$. in all LHC detectors would be that of non-pointing gamma(s) plus missing energy. Long TOF is one of the clear signatures for these processes. The MOEDAL slow decay detector would have to measure TOF's of 150 ns or more and TOF differences – between conventional, relativistic, particles from the intersection region and neutralinos that decay in the decay zone – of approximately 4 ns or more. A task that should be relatively easy for the TOF scintillator hodoscopes of the MOEDAL detector. The MOEDAL detector is designed to give an EM calorimeter energy resolution of $20\%/\sqrt{E}$. The gamma pointing resolution is $\sim 0.1^o$ for photons in the energy range 50-200 GeV.

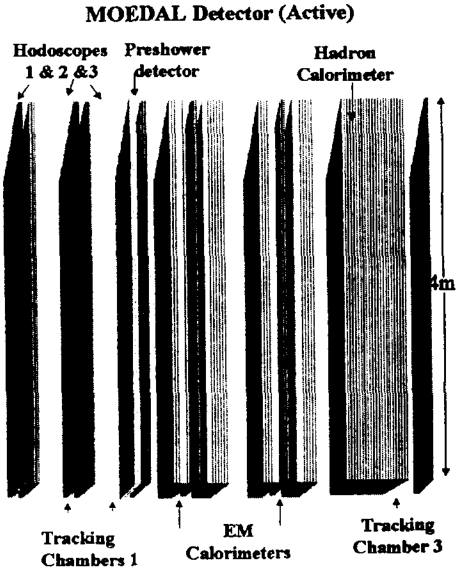

Figure 4. A sketch of the proposed active MOEDAL detector designed to slowly decaying and heavy stable particles.

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